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Today, laboratories use computers to manage test requests and specimen collection, control instruments, collect data from instruments, translate that data into meaningful results, collate all analyses on an individual patient, and generate reports for physician information and inclusion in patients' medical records. Because computers are part of every laboratory and because medical informatics (including clinical laboratory data) is essential to health care delivery, clinical laboratory personnel must have a basic knowledge of computers and computer communication technology. Individuals who understand how a computer operates will use computers more effectively and, when faced with decision making about computers, will not be at the mercy of those who do know. Similar to the automobile, the more you know about how it operates, the more informed decisions you can make in purchases, repairs, and upgrades. This chapter will present general concepts of computer hardware, software, and their usage in the clinical laboratory.

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CHAPTER 9

Computers in the Clinical Laboratory

Mark D. Kellogg

The clinical laboratory was one of the first areas in medicine in which computers were utilized. In the late 1950s automated instrumentation began to appear in the clinical laboratory and using computers to manage and store the data produced only seemed natural. Eventually, computers were used to support the entire process of analysis, from collection of the sample to reporting the results. However, computers of the 1960s and 70s were large devices requiring constant attention and cost significant dollars to purchase, install, and maintain. It was not until the personal computer revolution of the early 1980s that laboratory personnel had a powerful new tool capable of markedly improving their operation. With the advent of word processing, electronic spreadsheet, and database management software, computer systems moved rapidly into routine use in the administrative offices of most clinical laboratories. Concomitant with the development of the personal computer was the addition of microprocessor systems and associated software to control a new generation of complex laboratory instruments. Microprocessor-based instrument control systems replaced the electromechanical systems. These microprocessor-controlled instruments not only supported the transfer of data directly from analyzer to computer but also provided significant new abilities. Operators could now validate results before transfer, monitor and evaluate quality control, and be alerted to problems with key operational parameters of the instrument such as temperature, reagent volume, and missing samples.

Today, laboratories use computers to manage test requests and specimen collection, control instruments, collect data from instruments, translate that data into meaningful results, collate all analyses on an individual patient, and generate reports for physician information and inclusion in patients' medical records. Because computers are part of every laboratory and because medical informatics (including clinical laboratory data) is essential to health care delivery, clinical laboratory personnel must have a basic knowledge of computers and computer communication technology. Individuals who understand how a computer operates will use computers more effectively and, when faced with decision making about computers, will not be at the mercy of those who do know. Similar to the automobile, the more you know about how it operates, the more informed decisions you can make in purchases, repairs, and upgrades. This chapter will present general concepts of computer hardware, software, and their usage in the clinical laboratory.

The views, opinions, and/or findings contained in this chapter are those of the author and should not be construed as an official Department of the Army position, policy, or decision unless so designated by other documentation.

COMPUTER HARDWARE AND SOFTWARE

A computer is a machine with two key characteristics. It is designed to respond to a specific set of instructions in a defined manner and can execute programs that represent prerecorded instructions. The actual machine (wires, circuits, and transistors) is called the hardware. Software is the prerecorded set of instructions and data used to execute actions.

Hardware

Hardware is the physical part of a computer system. Computer hardware includes the following five main components: (1) memory, which allows the temporary storage of data and programs, (2) mass storage, for permanent storage of large amounts of data, (3) input devices, like the mouse and keyboard, that allow a user to enter data and instructions, (4) output devices, that let you see what the computer is doing, and (5) the central processing unit (CPU), which is the component that actually executes the instructions. Additionally, all computers require a **bus** to connect all of these components for transmission of data between them during processing, calculating, and other activities. A power supply provides the necessary electrical power for components to operate. The memory, CPU, and cards connected to the input and output devices are all connected to a circuit board called the **motherboard.**

Memory

Memory is that part of the computer where data is stored while being used and where programs or instructions for computer activities are stored. It consists of a number of physical units called chips. Memory determines the size and number of programs that can be retained by a computer and also the size of data that can be retained and processed at one time. The CPU directs the data manipulation that actually takes place in memory. There are different types of memory chips. Some retain their contents permanently after power to the computer is lost but most computer memory chips lose their contents when power is lost.

Read-only memory (ROM) is a type of memory that remains intact when power to a computer is discontinued. ROM memory remains permanently. Memory content of ROM is programmed at the time of manufacture and thereafter the user may not alter the contents. ROM contains instructions for operations essential to basic computer functions, for example, disk drive interaction. ROM chips are used to store **BASIC Input Output System** (BIOS) instruction, which is a set of routines that activate and control peripheral devices connected to the computer. ROM BIOS greatly affects computer compatibility with software. A rewriteable form of ROM, called FLASH-ROM, allows the contents of the ROM to be changed at a later time.

The smallest piece of information that is stored within a computer is called a **bit.** A binary digit (**bit**) is a single digit in a binary code (1 or 0). Physically, it is a memory cell and is electrically either on (1) or off (0). Eight bits of memory are required to store a **byte** or an alphanumeric character, which is the common unit of computer storage. In other words, eight bits represent one letter of the alphabet (one byte).

Random-access memory (RAM) is the working or user accessible memory of the computer and is lost when power is discontinued. Therefore, data that are in RAM must be saved before switching off the computer power. The user may enter, change, or erase data in RAM. The number of RAM memory chips is one of the major determiners of the cost of computers. Size of RAM not only determines the amount of data that may be processed at a time but it also dictates the size and number of programs that may be held in a computer at any one time. Microcomputers today usually come with at least 32 or 64 **megabyte** (MB, 1×10^6 bytes) RAM and are expandable to 256 MB or more. Just a few years ago computers came with only 1 MB or even as little as 640 **kilobytes** (KB, 1×10^3 bytes) RAM.

Microcomputers usually have empty slots in which additional RAM may be added after purchase. When acquiring memory chips, it is important to match their speed of operation with the requirements of the computer. The unit of speed is **nanoseconds** (1×10^{-9} seconds). The faster the chip, the more it costs. There are many kinds of RAM. **Static RAM** (SRAM) is a faster executing and more efficient RAM chip but it is costly. **Dynamic RAM** (DRAM) chips are more common, cost less, and are slower. DRAM has been succeeded by **synchronous dynamic RAM** (SDRAM) and **extended data out RAM** (EDO RAM); both improve the execution speed and amount of memory present in a chip.[1] Typically, memory chips are physically placed on circuit boards called memory modules. Each module contains eight or nine individual memory chips each containing 16, 32, or 64 megabits of memory. **Single inline memory module** (SIMM) and **dual inline memory module** (DIMM) are common modules found in today's computers. Almost all new computers use DIMMs. Most motherboards contain slots for only one type (SIMM or DIMM) but some contain slots to accept both. It is important to ascertain which type of memory a computer can utilize before adding additional memory modules

Virtual memory is a section of the computer's hard drive that is used to augment the existing RAM. The various operating systems (UNIX, Linux, Windows) handle this differently but essentially move data from physical memory, or RAM, to the hard drive when space in the physical memory runs low. Virtual memory is also used to swap out little used portions of physical memory to free it up for other operations.

Cache memory or **cache RAM** is a reserved section of the fastest RAM that is used to improve computer performance. Usually, parts of a program or pieces of data that are used repeatedly are read from a disk into cache memory and stored. Thereafter, each time the computer calls for these pieces of program or parts of data, they are immediately available from high-speed RAM rather than from the slower speed disk.

Storage Devices

As defined above, storage devices are hardware devices that hold or store data. These devices are rated according to the speed with which they react as well as to the volume of data they can accommodate. A **drive** is a peripheral device that receives data from the computer (output device), stores data (storage device), and feeds previously stored data to the computer (input device). Drives may be one of several types:

1. Floppy drives
2. Hard drives
3. Compact disc (CD) drives
4. DVD drives

Although less frequently used today, **magnetic tape** was a common form of data storage with early mini- and mainframe computers. Data that were no longer needed for daily processing were transferred to magnetic tape for archiving. Reels of tape were easier and safer to transport than large disk packs used for daily operation. Tape is linear storage and retrieval in contrast to the nonlinear or random processing of disk and hard drives. Magnetic tape may also be used to store data from microcomputers and is an economical means for backing up data on hard drives.

Floppy disk drives use disks that contain a disk media that is not rigid (as hard drives are) and may be removed and physically carried to different locations.[1] Earlier terminology referred to these disks as floppy diskettes or diskettes, but most people simply refer to them as floppy disks. The first floppy disks were either 8 in. or 5.25 in. in diameter and could store up to 400 kilobytes of information. Newer floppy diskettes are 3.5 in. and can store up to 1.44 MB. **Zip™** disks and **Jaz™** disks utilize a similar nonrigid disk media but can store 250 MB to 2 gigabytes (GB), respectively. The floppy disk is slowly disappearing as compact disk and DVD technology improves. Disks must be **formatted** or electronically divided into tracks and sectors before they can be used to store data. Disks must be matched with the type of drive in which they are to be used (for example, double density, high density, Zip™).

Hard drives store more data and store it more rapidly than do floppy drives. However, until recently, hard drives were not usually removed from the computer and carried around. A number of removable hard drives are now available, some even fitting into the palm of your hand. The disk media in the hard drive is inflexible and usually made of metal, although glass versions have been developed. The disk media is placed in a closed system (the floppy disk is open) that allows the disks to operate at greater speeds and to hold more data.

Compact disc (CD) drives use laser beams to read and write data. Each CD holds up to 650 MB of memory. The CD disk player is closely related to the well-known audio CD or compact audio player found in many homes. There are a number of varieties of CD drives, including CD-ROM (CD read-only memory), CD-R (CD-recordable), CD-RW (CD-rewriteable). CD-R is a type of WORM (write once, read many) type of technology that allows the user to record information onto the CD. CD-RW takes that capability one step further and allows the CD-RW disk to be erased and rewritten with new data. The CD-RW drive can write to the older CD-R disks but can rewrite only with the CD-RW disks.

DVD drives are the latest technology (1999–2000) and are beginning to replace CD drives. Most people call DVD either digital video or digital variable but the manufacturers state that DVD does not stand for anything.[1] The disks used in these drives are physically similar in size to CDs, but can hold between 4.7 and 18 gigabytes (GB) of information. Like the CD, these drives exist in different formats. The DVD-R (DVD-recordable) writes to a 4.7 GB disk once and then the disk can be read many times using standard DVD players. DVD+RW (DVD-rewritable) drives can read standard DVDs and also read and write to 3 GB DVD+RW media. DVD-RAM (DVD-random access memory) uses special media that cannot be used in other DVD drives, and can be written and read multiple times like RAM memory chips. The DVD-RAM uses both sides of the DVD-RAM disk, holding 2.6 GB on each side.

Input Devices

An input device is a peripheral device that sends data to the computer, for example, a keyboard or disk drive. Because input devices are sending data to the computer, a software program (driver) must inform the receiving computer of the communications parameters with which the input device transmits. These parameters will be discussed later in the communications section of this chapter. For an input device to function, it must be physically interfaced (connected) to the computer and a program called a **driver** that instructs the computer how to interact with the device must be loaded into memory.

The **keyboard** is that input device with which most computer users are familiar. In addition to the keyboard, almost all computers today also use a **mouse** to assist communication with the computer. There are at least three types of mice from which to choose. A **serial mouse** is connected to the serial port of the computer. A **bus mouse** connects to a special board that must be added to the computer. Therefore, a bus mouse requires inserting an extra circuit board or card into the computer motherboard. A **PS/2 mouse** plugs into the mouse port of IBM PS/2 computers.

A **bar code reader** is a device that directs a laser beam or a light beam across a series of lines of varying widths (the bar code) that code information. The reader directly enters the scanned information into an interfaced computer. Bar code devices are common to the laboratory and hospital environment. The bar code is a key element that allows automated instrumentation to identify specimen and reagent containers. **Microphones** are also used as input devices on today's computers, and as speech recognition technology improves, their use to control computer activity will be become as common as today's mouse input.

Monitors and Video Cards

A **monitor**, cathode ray tube (CRT), or screen is a display device that is used to enable the user to view the output of a computer. A monitor receives output data from the computer and is therefore an output device. A **video card** or **video adapter** is a plug-in circuit board that generates text and graphic images for a particular kind of monitor. It is important to match the video card to the software requirements and to match the output of the video card to a monitor. Damage may occur to a monitor if it is not connected to a video card to which it is matched.

Most computer systems today use **red-green-blue** (RGB) monitors that accept separate signals for each of the colors plus an extra, individual signal for synchronization. An **interlaced** monitor denotes alternately scanning or displaying all odd lines and then all even lines. Television uses interlaced technology and generates 60 half frames or 30 full frames per second. The screen is scanned from left to right, top to bottom every odd line, and then it is scanned again every even line. A problem with this technology is that if the scan rate is too low, the picture flickers. **Noninterlaced** monitors sequentially refresh all lines top to bottom and are flicker-free.

Video cards and monitors are selected and matched in relation to video resolution modes. **Resolution** is the degree of sharpness in image or printed letters and is expressed in terms of rows and columns of **picture elements (pixels),** which are the smallest entity or dot that can be displayed on a screen. Pixel resolution is expressed in rows and columns. Thus a video card that outputs an image with a resolution of 640 × 480 pixels is sharper than a video card that outputs an image of 420 × 380 pixels. In addition to pixel resolution, the **number of displayable colors** affects resolution perceived by the human eye. A 640 × 480 pixel resolution with 256 displayable colors has a higher resolution or sharper image than a 640 ×

480 pixel resolution with 16 displayable colors. Number of displayable colors is one of the video mode characteristics.

A method used to rate resolution of monitors is the dot pitch of the monitor. The **dot pitch** (dp) is a property of the monitor itself and is the width of a dot in hundredths of a millimeter. The smaller the dot, the sharper the image. Higher resolution monitors today have a 0.28 dp, which is 28/100 of a millimeter. The lower the dp, the better the resolution. A 0.28 dp monitor displays a sharper image than a 0.33 dp monitor. Displaying a 640 × 480 pixel image on a 0.28 dp monitor would produce a sharper image than displaying a 640 × 480 image on a 0.33 dp monitor.

Printers

Printers make hard, permanent copies of computer output and are rated according to quality or sharpness of print as well as to speed of printout. Quality of print may be denoted by the terms: **draft, near-letter quality,** and **letter quality** or, more precisely, **dots per inch** (dpi). Speed of printout is assessed as **page per minute** (ppm) or **characters per second** (cps). Very roughly, 1 ppm is equivalent to 60 cps.

Interfacing or connecting printers to computers requires matching communications parameters and is covered in the communications section of this chapter. Ability to print different fonts and to print in **landscape** (horizontal) or **portrait** (vertical) is controlled by software. Ability to print graphics is also software controlled, except that the printer must be capable of performing the software instructions, e.g., daisy wheel printers can never print graphics. Printers come in many types including daisy wheel, dot matrix, ink-jet, laser, and dye sublimation.

Daisy wheel printers form characters by selectively impacting letters located on the end of a spoke of a revolving wagon wheel. These printers are letter quality but are not capable of printing graphics because they do not print dot by dot or pixel by pixel. Generally, daisy wheel printers are faster and of sharper quality than dot matrix printers.

Dot matrix printers form characters by selectively impacting tiny wires, from a group of rows and columns of wires, onto a ribbon. The formed characters are actually a series of dots. They output a draft quality or readable text, which is the most rapid printout it can perform (200 to 600 cps or 2.5 to 7.5 ppm); however, the quality is poor because there are few dots per inch. The near-letter-quality print has more dots per inch, is sharper but is slower to produce (60–80 cps or 1 ppm). The ink-jet printer is a type of dot matrix printer that uses a head that sprays tiny droplets of ink onto print material. Ink-jet printers are much quieter than standard dot matrix printers, can make smaller dots to improve print quality, and the liquid ink can be mixed for color printing capability. However, they print more slowly than standard dot matrix printers and since they do not print by impact, they cannot print carbon copies.

Laser printers are quieter, nonimpact, and use the electrophotographic technology of copy machines to print a page at a time. They generally cost more, produce sharper images, and print faster than other printers. Laser printers print letter quality images of 300 or greater dpi. Laser printers have enabled a high quality in printing. Postscript is a page description language from Adobe Corporation. An application program uses the postscript language to describe text fonts and graphics images. For a printer to print a postscript document, it must have a CPU and memory to follow the application program's description in designing fonts and graphics. Both application program and printer must have postscript capabilities.

Other types of printers include thermal printers that burn images into a special paper. Thermal printers were quite common on instruments produced in the 1990s.

Modems

A **modem** is shortened terminology for a **modulator-demodulator,** which is a device that transforms digital data from the computer to analog data for transmission over normal telephone lines and analog data from the telephone line to digital data for use by a computer. Modems allow computers to communicate with other computers over telephone, wireless, and cable systems. Eventually, this modulation and demodulation will be unnecessary when digital transmission systems are more widely used. The digital signal level of a normal telephone line is 0 (zero) and allows for a maximum transmission rate of 64 kilobytes per second (Kbps).[1] To create lines capable of carrying a digital signal, copper wire used for telephone lines can be twisted into two pairs to create a **T-1** line capable of 155 megabytes per second (Mbps) transmission and can carry 24 phone lines.[1] A **T3** line combines 28 T-1 lines and can carry 672 different phone (voice) lines or up to 44.7 Mbps of data. Most **internet service providers** utilize T3 lines to connect to the main backbones of the Internet. Fiberoptic wires are also capable of carrying a digital signal.

Central Processing Unit

The **central processing unit** (CPU) is the brain of the computer where instructions are read, decoded and executed. Sometimes called the central processor, microprocessor, or processor chip, the CPU controls, coordinates, and performs computer operations including calculations, comparisons, and data transfer. Even though operations may actually be accomplished on other elements (e.g., a video card, a math coprocessor), the CPU directs data to and from those units and tells those units what to do and when to do it.

CPUs are characterized or rated according to the size of data (bits) they can process at one time and the clock speed (MHz) at which they process. Through the years, CPUs have technologically advanced from 8-bit (8088 chip) to 16-bit CPUs (80286 chip), 32-bit CPUs (386 and 486 chips), and

64-bit CPUs (Pentium and x86–64 chips). A 16-bit CPU can process twice as much data in a single step as an 8-bit CPU. It should be noted that for the larger CPU chip capacity to be realized, the software or program that instructs the computer must be written for that chip. CPUs are based on **complex instruction set computer** (CISC) or **reduced instruction set computer** (RISC) architecture. RISC-based computers split big complex operations into simple, tiny operations that can run 15% to 50% faster than CISC computers, and RISC chips are cheaper to produce.

Clockspeed of a computer is the speed of generated and spaced pulses that are sent throughout the computer. The CPU's clock or internal timing device governs the rapidity of machine cycles or speed of the processor. Computers with faster clockspeeds are able to perform more operations per second. Clockspeed is often used as a rating for the CPU. **Megahertz** (MHz, 1×10^6 cycles per second) is the unit for measuring clockspeed.

CPUs continue to be designed with faster clockspeeds, larger bit ratings, and smaller physical size. Early microcomputers use the 8-bit CPU (8088 chip) capable of processing 8 bits of data at a time and run at 4.7 to 10 MHz. The 386 machines run at 25 MHz and 33 MHz and 486 microcomputers run at speeds from 25 to 66 MHz. In the summer of 2000, chip manufacturers began to release chips with clockspeeds exceeding 1 gigahertz (GHz) and desktop computers will now far exceed the capabilities of even the largest minicomputers of just a few years ago.

Power Supply

All computers require a direct current (DC) power supply. Alternating current output from commercial electrical outlets is converted to DC by the power supply. The required wattage (size of power supply) varies with the number of boards and accessory devices that are plugged into or connected to the computer. Memory chips use 5 to 10 watts; each disk drive uses from 10 to 50 watts and each accessory board may use 15 to 25 watts. A typical microcomputer power supply is between 100 and 250 watts.

Bus

The **bus** is the computer's major circuitry or electrical paths along which data move between the various components. When purchasing any new card or board, one must match it to the bus. An industry standard architecture (ISA) is a 16-bit architecture of the older AT computers. The extended industry standard architecture (EISA) bus was 32-bit and accommodated EISA and ISA cards but no MCA cards. The VL-Bus and PCI (peripheral computer interconnect) have largely replaced the ISA and EISA cards. PCI though is limited in the number of slots that can be placed on a motherboard, and machines requiring a large number of peripheral devices will use the EISA system.

Types of Computers

Computers are usually classified by size and power into supercomputers, mainframe, mini, workstation, and personal computers. Advances in microelectronics now make distinctions ambiguous and the personal computers of today have far more computing power than the mainframes of even 10 years ago. The following definitions, then, will be generalities rather than absolutes.

SUPERCOMPUTERS

Supercomputers are the fastest type of computer available. These computers are very expensive and used in specialized applications requiring tremendous mathematical calculations. For example, weather forecasting requires a supercomputer. Other uses of supercomputers include animated movies, physics research, and medical modeling. In comparison to mainframe computers described below, the supercomputer uses its power to execute a few programs as fast as possible, whereas the mainframe computer is used to run many programs at the same time.

MAINFRAME COMPUTERS

The first computers were mainframes, e.g., Univac. Users interact or control mainframes via workstations called terminals, which may be either "dumb" or "smart." **Dumb terminals** are terminals without processing or computing capabilities. They consist of a keyboard by which the user gives commands to the mainframe and a monitor that displays user-entered commands and processing results. All calculations, processing, and storage are executed on the mainframe. In contrast, **smart terminals** are workstations that, in addition to the display and keyboard capabilities of the dumb terminals, provide some processing and memory capabilities independent of the mainframe.

MINICOMPUTERS

A midsize computer (minicomputer) in terms of size and power lies between the workstation and the mainframe. Technology advances have blurred the distinction between large minicomputers and small mainframes and between small minicomputers and workstations. In general, a minicomputer is a multiprocessor system capable of supporting from 4 to about 200 users simultaneously.

WORKSTATIONS

Workstations are typically used for applications that require moderate computing power and high-quality graphics. Examples include desktop publishing, computer-assisted design (CAD), computer-assisted manufacturing (CAM), and software development. Workstations generally come with a large, high-resolution graphics screen, large amounts of random access memory (RAM), networking capabilities, and a graphical user interface (GUI). Most workstations also have a mass storage such as a disk drive, but a special type of workstation called a diskless workstation comes without a disk drive. The most common operating systems for workstations are UNIX and Windows NT. In terms of computing power, workstations lie between personal computers and the minicomputer. High-end personal computers are equivalent to low-end workstations and high-end workstations are equivalent to minicomputers.

Like personal computers, most workstations are single-user computers. However, workstations are typically linked together to form a local-area network, although they can also be used as stand-alone systems.

In networking, *workstation* refers to any computer connected to a local-area network. It could be a workstation or a personal computer.

PERSONAL COMPUTERS

The last category of computers is the personal computer **(microcomputer),** which is the most numerous and well known. Microcomputers are easily moved, are able to stand alone (complete computers capable of processing, storage, calculating); however, they may also be connected to mainframe or minicomputers and they may also support a small number of user terminals. There is no temperature or humidity control requirement and costs range from $500 to $25,000. Examples of microcomputers are the IBM PS/2 series, Compaq, Dell, Gateway, and many more.

Software

Software is a written set of instructions for the computer. **Programs** are software that perform a specific task such as instructing the computer how to interact with a mouse, e.g. the mouse driver. Software is classified according to the task that it performs.

OPERATING SYSTEMS

An **operating system** is a master control program that organizes all activities of the computer and instructs the computer how to interact with peripheral devices, for example, disk drives, keyboard, and monitor. It is the minimum software required to run a computer. Some parts of the operating system are in ROM. Core parts of the operating system are loaded into the computer RAM from the disk on **booting** (turning the computer on) and are thereafter available from memory for immediate access. Other parts of the operating system are seldom used and may be loaded into memory as needed.

Operating systems set specifications to which application programs must be written in order for them to function. Some examples of earlier operating systems include: DOS, OS/2, and XENIX. Operating systems in common use today include various versions of Windows (95, 98, NT, 2000), UNIX, Linux, and the Mac OS. Application programs, e.g., word processing packages, written for one operating system will not run in any other operating system. OS/2 is an exception in that it does have a multitasking function that allows a user to run application programs written for DOS. UNIX and variations are largely run on mainframe and minicomputers, even though there is a version, called XENIX, that runs on microcomputers. It is expected that in the future operating systems will allow application programs to run on all types of computers. The tendency to interface all types of computers in networks is driving this trend for standardization of software.

LANGUAGES

A **language** is a system of symbols that is used for communication. There are different levels of languages for communication with computers. **Machine language** is the only symbolic code that the computer understands. For the computer to understand an instruction, it must be in machine language. Commands in machine language, however, are meaningless to most humans.

Assembly language was developed for the convenience of programmers. It resembles English and is more understandable to most humans than machine language. Instructions written in assembly language must first be assembled (translated) into machine language before a computer can understand them. Assembly language is sometimes called a **low-level language** because it is not far removed from machine language, e.g., one word in assembly language is translated into one word in machine language.

Pascal, BASIC, C++, and structured query language (SQL) are **high-level languages** that closely resemble English but are far removed from machine language, e.g., one word in high-level languages may be translated into several words in machine language. Instructions written in these high-level languages must be compiled (translated) to machine language before the computer can understand and execute them. C++ language can be compiled into machine language for almost any computer; therefore, C++ is a **transportable language** because it may be transported or run on almost any computer.

DRIVERS

A **driver** is a program that instructs the computer on interaction with a peripheral device. In addition to correctly interfacing or connecting a peripheral device with a computer, one must load a driver for each peripheral device before the computer is able to utilize it.

APPLICATION PROGRAMS

An **application program** is a program that is written for a specific purpose. There are many commercially available programs for general laboratory chores. If a laboratory can locate application software that does exactly what it needs, that software may be used. However, most likely, some tailoring of available software is required to match the individual clinical environments.

Word processing programs are programs for managing text documents and their printout. These packages may contain a spell checker, a thesaurus, and even a grammar checker. Most now contain a view-page function, which allows the user to view the layout of a page before printing. Because text is easy to move around, copy, delete, and correct, word processing has greatly decreased the time required to write documents. Some more common examples of word processing programs are Word Perfect™, Lotus WordPro™, and Microsoft Word™.

Electronic spreadsheet programs are programs that simulate paper worksheets of columns and rows of numbers for budgets and other financial bookkeeping. The spreadsheet is much larger than a single screen and can be scrolled through for viewing. Mathematical formulas may be added in a row or column of a spreadsheet and thereafter they are automatically calculated and the calculated result, not the formula, is displayed in that column or row. Electronic spreadsheets are useful and save time in planning, forecasting, and predicting because a manual change in a single value is automatically carried throughout the entire spreadsheet. Lotus 1-2-3™, Microsoft Excel™, and Quaatro Pro™ are popular electronic spreadsheets.

Database management programs are programs that organize, store, and retrieve data in a database. Common examples are FileMaker™, Microsoft Access™, Lotus Approach™, dBASE™, and Paradox™. Databases are used in numerous applications in the clinical laboratory, e.g., inventory and personnel scheduling.

Personal information manager (PIM) programs are programs that are designed to organize or manage one's personal job functions and calendar of events. Sidekick Plus™, Microsoft Outlook™, and Lotus Organizer™ are examples of PIM programs.

Lecture or seminar presentation software is a program used to prepare a series of computer illustrations to accompany a presentation. Usually, an overhead projector is used to display the computer output on a large screen for the audience. Microsoft Powerpoint™, Visio™, and Astound™ are examples of presentation software.

Statistical programs are written to perform statistical calculations. A common example is Statistical Analysis System or SAS™.

Netware programs are programs that organize and control communications over a network. Netware is also the commercial name for a commercial vendor's netware program. Examples of these types of programs are Novell's Netware and 3-Com's Ethernet Share.

Internet Browsers are programs that allow users to look at pages from the World Wide Web. Examples of these programs are Microsoft Internet Explorer, Netscape Navigator, Mosaic, and Opera. More specifically, these programs read Hypertext Transfer Protocol (HTTP) pages, usually from the Internet. The pages are written using Hypertext Markup Language (HTML) and allow the communication of text, graphics, and multimedia objects over the Internet. The Web is the channel of the Internet used to distribute these documents. More about the Internet will be discussed later in this chapter.

NETWORKING AND COMMUNICATION

Computer Networks

Today, computers almost never operate as stand-alone computers and are usually **networked** to other computers to share data, applications, and peripheral devices. The simplest configuration consists of several computers linked together in what is termed a local area network (LAN). This could be the computers within a "local" area like an office, laboratory, home, or even a small building. LANs are limited to physical distances between computers of less than 2 kilometers and usually use one protocol for communication. When computers are farther apart or multiple LANs are linked to each other, these networks are usually called wide area networks (WANs).

The ability to share expensive peripherals like laser printers, large mass storage, or Internet connections make networks a cost-effective solution to purchasing such devices for every computer. Bridges, routers, and switches are used to connect LANs together (to form WANs) or to connect segments of LAN that are separated by distances greater than those allowed. The bridges, routers, and switches route the data packets traveling through the cables to the proper segment of the LAN or across LANs based on the destination address found within the data packet. When data must travel across networks using different communication protocols (like a LAN to the Internet), then a gateway must be utilized. The gateway is a computer that is connected to both networks and translates the data from one before transmitting to the other. The connection of your laboratory network to the Internet would be handled by a gateway.

Networks are categorized by three characteristics: architecture, protocol, and topology. Peer-to-peer and server/client are two architectures commonly found in networks. The simplest architecture is the peer-to-peer network that connects small numbers of computers. This system allows the hardware (printer, CD-ROM, fax-modem) attached to any computer on the network, to be shared with other computers on the network. Users can also share data stored on their hard drives. The peer-to-peer network is easy to configure and most personal computers come with the necessary software. Additional hardware requirements are a network card and cabling to connect the network cards. Security of information is a concern with peer-to-peer networks. The peer-to-peer system works well only with limited numbers of computers, usually less than 12.

Server/client systems have one central computer (server) that provides various services like e-mail, printers, and Internet access to the other computers on the network (clients). In this system, the data and programs are held on the server and not the individual user computers. While providing a higher level of security, this system is more vulnerable to power failures and hardware failure. If the server is not functional, all data and programs stored there are unavailable. Critical data and programs may be mirrored on other computers within the network to provide backup if the main server crashes. The client/server system is the most common network architecture.

Protocol refers to the common set of signals and rules that the network uses for communication. Your choice of protocol is dependent on what system you are using. **Ethernet** was one of the first protocols developed for connecting computers.[1] Various modifications have been made on the original since its development in 1972 and is still in common use today. **NetBEUI** was developed by IBM for use with small- to medium-sized networks and is very easy to configure.[1] The protocol suffers from network congestion when you have more than 20 machines on the network. The **IPX/SPX** protocol was developed by Novell for use with its Netware systems. This is usually the default protocol when you are using the Microsoft Operating systems on networked computers. IPX/SPX is more difficult to configure and is largely being replaced by **Transmission Control Protocol/Internet Protocol** (TCP/IP). TCP/IP was originally developed as the transfer protocol for the Internet and has now been adapted for controlling transmission in LANs. It allows communication between dissimilar computer systems and can be easily scaled up to handle increasing numbers of machines.

Topology refers to the geometry used in configuring the network. Common topologies are star, ring, and bus. See Figure 9–1 for examples of these topologies. The Internet is actually a network topology and does not physically exist without the connections between the millions of computers using TCP/IP to communicate.

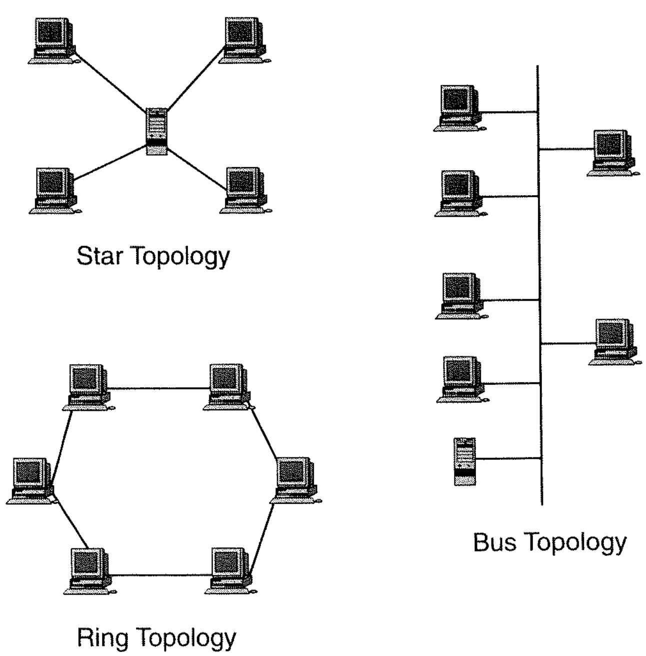

FIGURE 9-1

Microcomputers connected in various types of network topology.

Computers that are attached to the network require a network interface card (NIC) to which the network cable is connected. In a peer-to-peer network, these cards are connected to each other via the cable. In an Ethernet network, the cables are attached to network hubs that manage the receipt and transmission of data from the various computers. Ethernet networks can use three different types of cabling. Unshielded twisted-pair (UTP) is the most common and least expensive. Shielded twisted pair and coaxial cable can also be used. Both of these cables are shielded from electromagnetic interference (EMI). EMI is usually not a problem in offices or homes but within the clinical laboratory, significant EMI can be generated with the number of motors, instruments, and other devices present. Be sure to consider the possibility of EMI when selecting cabling for use in the clinical laboratory environment. Coaxial cabling, also called thin Ethernet, must be configured in the ring topology, making it more difficult to set up. Additionally, the cables and connectors must be protected because any break in the chain will cause the network to fail.

Communications

Communication or transmission of data between a computer and any other device, whether it is a laboratory analyzer, a laboratory specimen identification label printer, a patient identification plate printer or even another computer, utilizes similar technology and communication parameters. The goal of this section is to provide the laboratorian with sufficient information to understand communications between computers and with laboratory instrumentation.

All input to computers is converted into binary numbers made up of the two digits 0 and 1. Binary code is made up of the two digits 0 and 1. The 1 bit is transmitted as pulses of electricity of high voltage; the 0 bit is transmitted as no pulse or low voltage. In memory, the 1s and 0s are stored as a series of charges (on) and no charges (off). The American Standard Code for Information Interchange (ASCII) is a binary code for data that is used in most minicomputers and in all microcomputers. Another binary code, Extended Binary Coded Decimal Interchange Code (EBCDIC), is used by IBM mainframe and some minicomputers. ASCII has 256 different characters, of which the first 128 are standardized for all computer platforms. The first 32 are control codes used for communications, text formatting, and printing controls, such as making the computer beep. The next 96 characters are used for numbers, letters, and standard punctuation marks. Codes 128 and higher are nonstandard at the present time and are therefore highly vendor dependent. Character data such as letters and punctuation marks are stored in memory or files as the ASCII bit notation, but numbers must be converted to binary bit notation for the computer to utilize them (Table 9–1).

TABLE 9-1

Binary Bit Notation for Decimal Number 10

Bit number	7	6	5	4	3	2	1	0	
Value of bit	128	64	32	16	8	4	2	1	
Binary value	0	0	0	0	1	0	1	0	
Decimal value	0	0	0	0	8	0	2	0	
Sum in Decimal	0	+0	+0	+0	+8	+0	+2	+0	= 10

Types of Computer Communications

In addition to collecting and processing analytical data, clinical laboratory computers are largely used for communicating those data. The International Standards Organization (ISO) has defined a communications reference model, the **Open System Interconnection (OSI),** which is a 7-layer standard for computer communications protocol (Figure 9–2). This model was developed to encourage standards in communications software and hardware so that multivendor products might be interchangeable and interconnectable. Of the 7 protocol layers, 1 and 2 describe basic communication of a computer with any other device and in the clinical laboratory and are most likely the responsibility of clinical laboratorians.

Layer 1 defines the **physical layer** or the actual set of wires, plugs, and electrical signals for sending and receiving devices. Layer 1 is the cable connection of computers to peripheral devices and is dictated by the protocol used in layer 2.

Layer 2 describes the **data link layer** or the transmission of a block of data from one device to another. Data are packaged in blocks of specific length. Codes for start of data block, for end of data block, and for error checking are appended to each block before transmission.

The types of data link layers are asynchronous transmission and synchronous transmission. **Asynchronous transmission** originated with the mechanical teletype machines and is the transmission of one character at a time over a single wire. The serial port on a microcomputer is the normal asynchronous communication channel. This is the type of communications commonly used between two computers, between two modems, and between most laboratory instruments and computers.

Synchronous transmission was developed for higher speeds and higher volumes of transmission and is the transmission of blocks of data over multiple wires with both sending and receiving stations synchronized to each other. Synchronous transmission involves extensive error checking. This is the type of communications used to transfer data internally by the computer and used to send data from computer to printer.

Transmission Types

Transmission of data may be either parallel or serial. **Parallel transmission** is the concomitant transfer of multiples of 8 data bits or bytes at once over 8 parallel lines. **Synchronous communication** is parallel transmission and requires both sender

7. APPLICATION	Provides electronic mail and distributed services
6. PRESENTATION	Performs data conversion to and from different formats
5. SESSION	Establishes and terminates session
4. TRANSPORT	Provides end-to-end control
3. NETWORK	Routes data to the appropriate destination
2. DATA LINK	Transmits data reliably between adjacent nodes
1. PHYSICAL	Connects nodes physically and electronically

FIGURE 9-2

Open System Interconnection (OSI) communications reference model. The 7 layers are shown with short descriptions. Layers 1 and 2 are required for any transmit and receive communications.

and receiver to be synchronized. Parallel transmission is used to transmit data within a computer and to transmit computer output to a printer. All internal computer data transmission is parallel. The CPU determines what size **word** (bit size of transmission) may be transmitted at a time, e.g., 8088 CPU transmits 8 bits at a time, 486 CPU transmits 32 bits at a time. Although parallel communication is more rapid, the cost of its multiwire cabling is more expensive than that for single-wire serial communication. The OSI standard for parallel interface is the **Centronics** 36 pin. Originally, the parallel port on computers was a 36-pin connector and used a ribbon cable to interface with peripheral devices. Today, a 25-pin female D socket, **DB-25S,** serves as the parallel port on most computers. Some printers still have the Centronics 36-pin connector, whereas many have the 25-pin connector. The parallel port is relatively slow for data transmission and is limited to 512 Kbps.

Serial transmission is data transfer bit by bit or one bit behind another over a single wire. **Asynchronous communication** is serial transmission and does not require synchronization of sender and receiver. Although parallel communication meets the needs for higher speed data transfer, it is most cumbersome, expensive, and difficult to implement over long distances (300 to 500 feet). Modems, mice, and most laboratory instruments utilize serial communications. A communications card converts data from the parallel format within the computer to serial format that is sent to peripheral devices. That same card receives serial formatted data (from laboratory instruments) and converts it to parallel data for use within the computer. The **RS-232** (Figure 9–3) or RS-232-C is the OSI interface standard for serial asynchronous communications. Most microcomputers have two serial and one parallel port. The RS-232 port on a computer is a 25-pin male or DB-25 port. Since all of the 25 pins are not used in communications, a 9-pin male DB-9 serial port has been developed and is also used on microcomputers. DB-25 to DB-9 converters are available, if needed, to accommodate or match serial cables, sockets, and ports. The universal serial bus (USB) connector is replacing the serial and parallel cable for data transmission at low and medium bandwidth requirements. USB can achieve transfer rates of 12 Mbps and the cable can also be used to transfer power to the peripheral device. The ability to add and remove peripherals without shutting down the computer is also allowed with USB. This is called "hot swapping." Additionally the USB system takes full advantage of the "plug and play" capabilities most operating systems now employ and no longer requires opening the hardware to add new peripheral boards, setting of switches inside the computer, and other elaborate configuration processes.

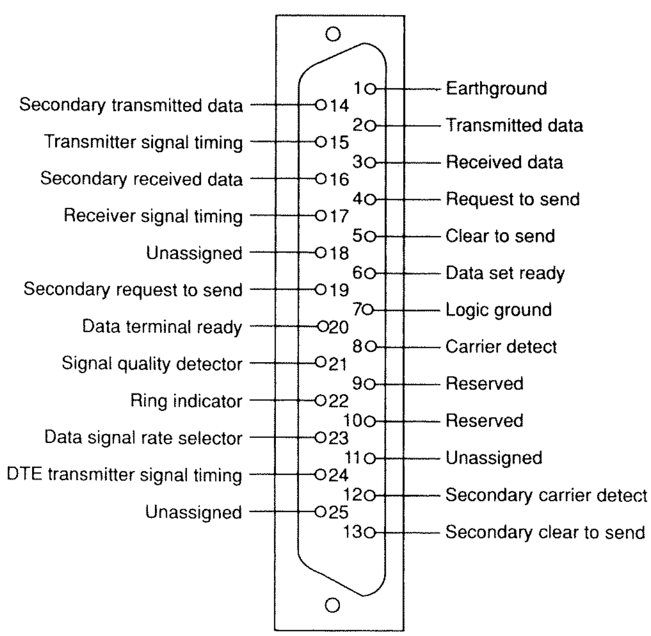

FIGURE 9-3

RS232 Standard. The pin numbers and functions assigned in the RS232 standard are shown. Some of the 25 pins are reserved and some are unassigned.

Communication Parameters

Sending and receiving devices must be matched or set to the same communication parameters, which are:

1. Baud rate
2. Parity
3. Data bits
4. Stop bits
5. Duplex (full or half) or echo (on or off)

When running communications software, the parameter information must be entered before transmitting and receiving. A description of the parameters follows.

Baud rate is the switching speed of a communications line. Originally baud rate was equivalent to the transmission speed of asynchronous communications in **bits per second** (bps). Newer technology provides more rapid transmission rates and allows one baud or one electrical switching of a communications line to transmit more than one bit. Therefore, at today's higher transmission speeds, baud no longer is equivalent to bps.

A **start bit** is a bit that is added to the beginning of a character before it is transmitted in asynchronous (start/stop) communications. A start bit signals the beginning of a transmission and alerts the receiving device that a character is coming. The start bit is a logical 0 and has a negative voltage.

A **stop bit** is a bit that is added to the end of a character before it is transmitted in asynchronous (start/stop) communications. A stop bit signals the end of a transmission to a receiving device. Communications programs must know how many stop bits are being used. The stop bit is a logical 1 and thus has a positive voltage.

The **number** of data bits is the number of bits used to represent data in communications. For most microcomputer asynchronous communications, 7 data bits are used to represent a character and one bit is a stop bit. The number of data bits used by laboratory instruments is generally given in the accompanying manual.

Parity is the quality of being odd or even. In asynchronous transmission, parity is an error detection method. The sending device checks the number of 1s or 0s and, when necessary, adds an extra parity bit to make the number odd or even. The receiving device then checks for odd or even parity. A **parity bit** is an extra bit attached to the byte, character, or word for error detection in transmission.

A **frame** is the bit length or size of a package of data that is transmitted at one time. Although the length of a frame can vary, nearly all modern clinical laboratory instruments and all microcomputers use a frame of 10 bits. Because the communication is asynchronous and may be sent at any time, there is no clock pulse. For the receiving device to be able to read the communication, it must be given the parameters (baud rate, number data bits, and number stop bits). The start bit signals the beginning of a frame and thereafter the given parameters tell the receiving device what bits to read as data.

Duplex is a term describing the direction of communication between two computers. Full duplex is simultaneous two-way communication, e.g., telephone communication. In **full duplex,** characters sent are reflected back from the receiver before being displayed on the sender's screen. In **half duplex,** data travel only one way, and therefore cannot be transmitted and received simultaneously. In half duplex, data are simultaneously sent to the receiver and to the sender's screen. The receiver does not echo back the data for display.

Echo is a method whereby the transmitting device may view the outputted communication. When transmitting and not seeing the outputted transmission, turn **echo on.** If everything is displayed in duplicate, turn **echo off.**

Uploading is the sending of a file to a central computer from a computer at a remote site. **Downloading** is the copying of a file from a central computer to a computer at a remote site.

LABORATORY INFORMATION SYSTEMS

The term **Laboratory Information System (LIS)** can be used to describe a system that uses computers to connect laboratory instruments and computers and process the data associated with requesting tests and reporting results. Laboratory information systems can be very simple or highly complex but all have the basic components of a network as discussed in the previous section. The system requires hardware (computers, input/output devices, and peripherals), connections between devices and computers, operating system software, a communication protocol, and a format for data transmitted through the network. In addition, the LIS may be connected to other systems like the Hospital Information System (HIS), other laboratory LISs, or the Internet.

Because many of these systems were originally designed in isolation from the others, there are significant differences between protocols and data formats. Attempts have been made to standardize the format of data within clinical information systems so that LISs and HISs and others can all communicate without error. One example of this is the **Health Level 7 (HL-7)** message protocol. Another example of attempts to standardize the data between laboratory systems is the **Logical Observational Identifiers Names and Codes (LOINC)** database developed at the Regenstrief Institute. This database provides a standard set of names and codes for laboratory results (e.g., bilirubin, amylase, calcium).

MEDICAL INFORMATICS

Although data and information generated by the clinical laboratory constitute a large part of health care data, it is not the only contributor to these data. Radiology reports, patient history, electrocardiogram reports, and journals all contribute to the massive amounts of data generated in the health care system. Perhaps one of the most important roles for computers has been and will be the management of this information so that health care professionals can effectively acquire, store, retrieve, and utilize the available data and information. Out of this need to access and utilize health care information emerged the field of medical informatics. Although early pioneers in this field began work in the 1950s and 1960s, it was not until the 1980s and 1990s with improvements in computer technology and telecommunications that medical informatics became widely recognized. The term *informatics* originated in 1968 to describe the concept of information science and was later defined to be "the discipline of science which investigates the structure and properties of scientific information."[2] As such, medical informatics would then investigate the structure and properties of medical information.[3]

The term *medical informatics* is often used to describe the use of computers in medicine. However, medical informatics goes beyond the use of computers and the relatively simple collection, storage, and retrieval of data and information. The field is not concerned with the equipment that is used but the information and how it is acquired, utilized, and stored. Medical informatics attempts to bring together information and the necessary tools to the decision-making process in health care.

Informatics (and medical informatics) views the computer as a tool, much like the microscope is a tool in the clinical laboratory.[3] Computer technology is viewed as "enabling us to explore and better understand the informational and cognitive foundations of medicine."[4] The field of medical informatics is rapidly evolving as computer and communication technologies allow access to greater numbers and larger databases of information. The field is actively working to provide health care practitioners the information they need, when they need it, and in a form that is easily interpreted and used for problem solving and decision making.

In the clinical laboratory, informatics can be used to help determine how data should be presented to the user. Some examples of clinical laboratory questions that can utilize informatics:

- Is a bar graph better than simple text to present lab results?
- Should reference ranges be included with lab results?
- How should critical values be displayed to attract attention on a report form?
- What additional laboratory tests should be ordered to complement the current results?
- How can we present large data sets to technologists and technicians to rapidly scan for errors, trends, or other problems?
- How can we acquire data from all laboratory tests performed on a patient over time at different locations so a physician has all results applicable to the decisions without overwhelming them with data?

The clinical laboratory provides a wealth of information, and informatics is the process through which we can assure the most efficient utilization of the information. As genetic information is added to the output of laboratory data, we will be faced with even greater demands for "processing information." The laboratory cannot simply provide numbers but must provide a value-added resource of information to the health care practitioner. By adapting a definition used in nursing informatics,[5] we can define clinical laboratory informatics as a combination of computer technology, information science, and clinical laboratory science used to assist in the management and processing of clinical laboratory data, information, and knowledge to support the practice and delivery of health care.

SUMMARY

Because the systematic processing of information is critical to the health care delivery system and because computers play a substantial role in this information processing, clinical laboratory personnel must have a basic knowledge of computers and computer communications.

Basic components of a microcomputer include the power supply, the central processing unit (CPU), memory (RAM and ROM), video cards, monitors, storage devices (floppy drives, hard drives, CD ROM drives), input devices (bar code readers, mice), printers, and busses. Most of the computer components are rated according to their throughput speed. For best comparison of computers, one should select a software program that performs a task and run that program on all computers being compared. Because all components of a computer contribute to the total efficiency, timing the performance of a specific software task is the only valid method to compare efficiency of different computers.

Operating systems and languages are used to instruct the computer in its activities as well as in its interaction with peripheral devices such as laboratory instrumentation. Each peripheral device requires a driver (software instructions) be installed to inform the computer of interactive procedures.

Various application programs are commercially available to perform tasks. Major categories are word processing, personal information management, spreadsheet, statistics, and communications. The clinical laboratorian will evaluate the task and then select appropriate software to perform that task. Very seldom is a tailored commercial product available. Most likely, a generic program will have to be altered to meet the individual laboratory's specifications.

Computers are usually networked to other computers to share data, applications, and peripheral devices. Networks can be local (LAN), cover wide areas (WAN), or span the globe (Internet). Networks are classified by their architecture, communication protocol, and topology.

The Laboratory Information System can be used to describe a network of computers connected to each other and laboratory instruments to acquire, validate, interpret, and communicate the information generated by the testing process. Laboratory Information Systems are often connected to other clinical information systems. To assist in the communication of information between these systems, standardized message protocols like HL-7 and LOINC have been developed.

Medical informatics studies the structure and properties of medical information. It works to optimize how data is acquired, stored, and retrieved so the large amounts of data and information generated are available to health care professionals when and where they need it. The use of computer and communication technology is a key aspect of medical informatics practice, but it also is concerned with the human aspects of how information is used in decision making.

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